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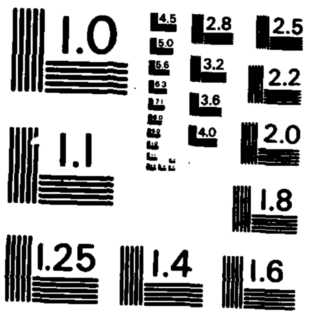

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DEPOT THROUGHPUT MEASURES
FOR DISTRIBUTION SYSTEM ANALYSIS

October 1982

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EXECUTIVE SUMMARY

Materiel distribution within the DoD encompasses five separate distribution systems, one for each Service and one for the Defense Logistics Agency (DLA). The cost of receiving, storing, issuing, and distributing defense materiel exceeds one billion dollars annually.

Recent efforts to improve the efficiency of DoD materiel distribution have been impeded by several technical issues, including the absence of uniform measures of depot throughput costs and capacities. As a result, proposed depot and inventory realignments, which would yield estimated savings approaching $100 million per year, have not been implemented.

To correct deficiencies in depot throughput measures, we propose that cost per hundredweight by functional product group be used as the measure of depot throughput cost. We also propose that depot throughput capacity be measured in hundredweight of processing capability per year. Functional product groups must be defined to include all materiel requiring similar handling and processing within a depot, from receiving through shipping. These measures are consistent with distribution system modeling requirements.

Existing reporting systems do not provide measures of depot throughput costs and capacities in the required formats and it is difficult to justify changing the reporting systems to capture this information. Because of the long-range planning context of distribution system studies, we propose that the depot throughput measures be derived from existing historical data as part of each study system analysis. Derivations can be made using a statistical or engineering technique, or a combination of the two, depending upon the specific objective of the analysis.

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1. INTRODUCTION

The DoD materiel distribution system is one of the most complex physical distribution systems in the world. It encompasses five separate distribution systems, one for each Service and Defense Logistics Agency. ~~(DLA)~~. Annual system costs are estimated to exceed one billion dollars.

The DoD Materiel Distribution System (DoDMDS) study sponsored by the Joint Logistics Commanders in 1978 reported that the distribution requirements of the Services and DLA could be satisfied at substantial cost reduction, close to $100 million annually. Those savings could be achieved through depot consolidations, inventory redeployments, and altered transportation arrangements. The recommended program to capture those savings was never implemented, however. The methodology used by the study team could not withstand several technical challenges, including the team's method of treating depot throughput costs and capacities.

As an outgrowth of the DoDMDS study, the Principal Deputy Assistant Secretary of Defense (Manpower, Reserve Affairs and Logistics), ~~PDASD(MRA&L),~~ in 1979 requested the Defense Logistics Analysis Office ~~(DLAO)~~ to prepare a long-range study plan for improving materiel distribution within the DoD. The development of valid measures of depot throughput costs and capacities is one task in that plan. This report describes the throughput measures we propose be used in future studies of the DoD materiel distribution system.

2. KEY FINDINGS

MODELING THE DOD DISTRIBUTION SYSTEM

The long-range study plan for improving materiel distribution within the DoD is intended to increase physical distribution analytical skills in the DoD and to answer specific questions. Major questions requiring answers are:

- What transportation cost reductions can be achieved through inventory redeployment?
- What are the optimum stockage location policies in terms of responsiveness and economy?
- What is the optimum wholesale/retail physical distribution interface?
- What surge/expansion capability is needed for mobilization?

Answering questions of this magnitude and complexity requires a variety of technical approaches, including modeling of the DoD materiel distribution network. Discussions with various DoD representatives confirmed that measures of depot throughput are to be developed in anticipation of future distribution modeling efforts. Consequently, measures of depot throughput must have the flexiblity to meet network modeling requirements.

SUBSTANTIAL RESOURCE COMMITMENT REQUIRED

Large-scale network modeling is required to assess cost tradeoffs among depot openings or closures, repositioning of stocks, and altered transportation arrangements. One attempt to apply network modeling concepts to the DoD distribution system was the DoDMDS study. That effort spanned three years (1975-1978) and cost about ten million dollars.

Future DoD distribution modeling efforts are also likely to require substantial resources. The application of those resources needs to be coordinated closely to ensure that the modeling efforts are successful. For instance, the most appropriate technical approach to establishing throughput measures depends largely on other research-related issues. To select one approach to measure throughput without considering other research issues will likely result in both efforts not being successful. To assume that a series of loosely coordinated tasks will result in a successful modeling effort is overly optimistic.

TWO DEPOT THROUGHPUT MEASURES REQUIRED

A number of network models are suitable for examining the DoD distribution system. The DoDMDS study group selected the Multicommodity Distribution System Optimizer Model (MDSOM) developed by Professors Arthur M. Geoffrian and Glen W. Graves. The selection process was based on the research objectives of the study, the size and nature of the network under analysis, and practical considerations of model development and implementation. DoD has retained contractual rights to the software and documentation of this model.

Although future DoD-wide distribution modeling efforts would probably use the MDSOM model, a review of other distribution models was conducted to assess the required inputs related to throughput. We found that distribution models all have similar input data requirements.

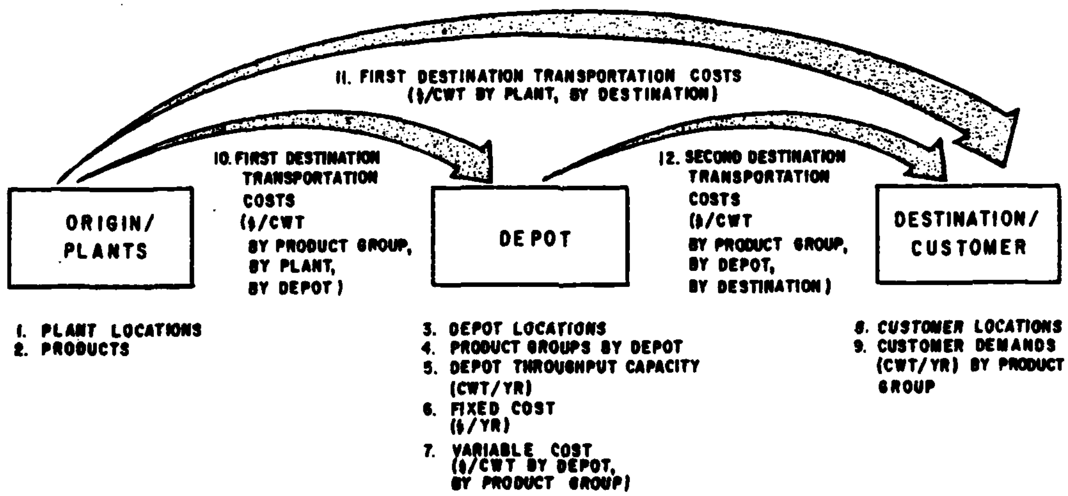
Figure 2-1 shows the inputs and measures required to model a distribution network. All feasible materiel movements from the manufacturer's plants to DoD depots and customers must be identified. The number of different items (3.7 million national stock numbers) in the DoD system requires that they be aggregated into product groups. For each product group, baseline or historical transportation costs, expressed in dollars/hundredweight ($/cwt), are required. Inputs are needed for both first and second destination transportation costs.

Two depot throughput inputs are required:

- Throughput Costs. This input is also referred to as depot variable cost (see Figure 2-1, item 7). It is expressed in \$/cwt by product group by depot.

- Throughput Capacities. This input (see Figure 2-1, item 5) constrains the distribution model to meet real world operating considerations. Throughput capacity is expressed in total cwt/year of processing capability for each depot.

FIGURE 2-1. DISTRIBUTION MODEL INPUTS



Since distribution models are used to assess tradeoffs between transportation costs and depot throughput costs, the same unit of measure (\$/cwt by product group) is required. Thus, modeling the DoD distribution system requires an aggregation of separate line items into commodity or product groups and the estimation of depot throughput costs and throughput capacities for those product groups.

REPORTING SYSTEM CHANGES NOT JUSTIFIED

Existing reporting systems do not provide depot throughput information in the format required for distribution modeling. The Services and DLA collect throughput costs by function (i.e., receiving, packing, bulk issues, etc.). They do not collect costs by item or by product group nor have they established by item or product group the manner in which materiel moving through a depot burdens throughput capacity. Private industry operates in much the same manner. Few commercial enterprises report distribution activity related to throughput in a format required for network modeling.

It is difficult to justify changing existing reporting systems to generate, on a recurring basis, throughput costs and capacities by product group. In the first place, doing so would require definition of a set of product groups and assignment of each line item in the distribution system to a group. Secondly, distribution modeling, particularly in a network as complex as the DoD system, is (should be) used as a long-range planning tool. It is not a continuing process -- more likely, a network modeling effort will be done on an *ad hoc* basis. In addition, the definition of product groups may well vary from one long-range planning exercise to the next because the scope and objective of analysis may shift. Under these circumstances, it would not be cost-effective to change ongoing reporting systems to generate information exclusively for network model input. Rather, it seems prudent to devise a system whereby throughput can be measured using routine historical data, leaving only the definition of product groups to be tailored to the specific objective of an analysis.

ALTERNATIVE APPROACHES

Three alternative approaches exist for converting historical information into the required depot throughput measures: a statistical approach, an engineered approach, and a combined approach. With all three approaches, depot items are classified into functional product groups (FPG). An FPG is defined to include all items which receive the same or similar processing functions within the depot, from initial receipt to final shipment. The general merits of each approach are briefly described below. Details of each approach are discussed in the following chapter.

Statistical Approach

This approach predominates in private industry. It estimates throughput costs and capacities from historical information using multiple regression analysis. Regression analysis is used to allocate total depot variable costs among FPGs. The allocated variable cost for each FPG is then divided by the hundredweight of that FPG issued to establish the required throughput cost measures (in \$/cwt by FPG). Throughput capacities are estimated by multiplying the hundredweight of materiel for each FPG by its respective throughput cost (\$/cwt).

The statistical approach requires few resources and has met the test of reliability in private industry. A major disadvantage is that it cannot be used to estimate throughput costs and capacities for more than about ten FPGs. It also requires off-line analysis to determine if a particular depot can process the assigned workload developed from the modeling exercise.

Engineered Approach

The engineered approach is rarely used in private industry. The technique is based on engineered simulation of materiel moving through a depot. A separate simulation is made for each FPG.

This approach permits identification of the direct variable costs for labor, equipment, materials, and space based on appropriate workload measures (i.e., issue, cubic feet, pallet, etc.). The direct variable cost is then allocated a portion of indirect variable costs and converted to a \$/cwt measure. Each product group must then be related to the FPGs to establish its throughput cost (in \$/cwt). Throughput capacities are estimated by multiplying the hundredweight of each FPG by its throughput cost.

The primary advantage of the engineered approach is its credibility. Key decision makers and operating personnel tend to understand and accept engineering concepts and approaches. Its principal disadvantages include the enormous effort to perform the analysis and the difficulty of establishing a benchmark against which alternative system configurations can be measured. Unless the engineered costs can be equated to known historical cost, the modeler cannot verify that the distribution model has been structured correctly and accurately portrays the distribution system.

Combined Statistical/Engineered Approach

This approach combines the advantages of the statistical and engineered approaches, while avoiding many of their limitations. An engineered analysis is used to derive workload weighting factors for each FPG. A weighted workload for each depot is then calculated using the FPG weighting factors and FPG workloads. Statistical methods are used to relate historical depot costs to the weighted workloads and to derive the necessary throughput cost (in $/cwt) for each FPG.

RESEARCH RELATED ISSUES

All three approaches -- statistical, engineered, or combined -- are acceptable for estimating depot throughput measures. The preferred approach is likely to depend on other modeling decisions, strategies, and research-related issues. Three topics warrant further discussion.

DoD System-Wide Feasibility

The number of transactions, depots, transportation links, and product groups requires extensive averaging to describe the distribution system in reasonable terms. For a system as complex as the DoD's, the amount of averaging may result in masking the true nature of the system and lead to questionable results and interpretations. Indeed, a review of the DLAO appraisal of the DoDMDS study shows that much of their criticism is leveled at actions taken to average the aggregate system transactions into a manageable set of costs and materiel flows. In spite of these criticisms, we conclude that it is feasible to accurately model the DoD distribution network for purposes of assessing cost-saving opportunities. A key question, however, is whether the network should be modeled on a system-wide basis or partitioned to lessen system averaging and enhance model results. A decision to partition by geographic area or by Military Service, for example, will influence the techniques used to estimate throughput measures and other model inputs.

Product Groups

The aggregation of approximately 3.7 million line items into a manageable number of product groups represents a major research endeavor. Two factors will influence the establishment of those groups: management considerations and materiel physical characteristics.

Preservation of Federal Supply Class (FSC) entities is a primary management consideration in the DoD distribution system. Preserving FSCs will enhance the interpretation of distribution model results, particularly in the area of inventory deployment.

The importance of defining product groups based on physical attributes (i.e., weight, cube, price, density, physical dimensions, etc.) arises because both transportation and depot processing costs are influenced to a large extent by the physical characteristics of the materiel. Since distribution network models assess tradeoffs between transportation and depot costs, the product groups must be so structured that comparable costs are developed.

The issue affecting which approach to use for estimating throughput cost and capacity concerns the number of functional product groups required to conduct throughput cost analysis. If the number of FPGs is more than about ten, the validity of the statistical approach may be compromised and throughput measures will have to be estimated using the engineered or combined approach. On the other hand, if the number of FPGs is ten or less, all of the three approaches are feasible.

Discrete Versus Average Throughput Costs

Modeling a distribution network requires a number of critical assumptions, many of which influence the inputs to the model. For instance, the DoDMDS study team assumed it was appropriate to establish a system-wide average throughput cost for each product group. That assumption, in effect, removed throughput costs from the optimization process, which resulted in an optimization of the distribution network based on cost trade-offs between transportation and depot fixed costs only. That approach, although not ideal, is also not uncommon, particularly when a diversity of products exist and not all products are received or issued from every depot.

To test the sensitivity of its assumption, the DoDMDS study group adjusted the product standard variable costs by a wage grade multiplier. The wage grade multiplier essentially changed the average depot throughput costs to depot specific or discrete throughput costs. The adjusted standard product throughput costs may not have accurately represented the variance of throughput costs from depot to depot, but it did introduce an element of discrete throughput costs to the modeling strategy. The DoDMDS study group compared the model run results using the adjusted throughput costs to the objective (optimized) system and concluded,

> "...the shifts did not produce a structural change. The total system cost was only 0.2 percent lower with the wage grade differentials than the objective system using standard variable costs. Once again, the objective system structure was found to be stable within the tested range of an important input variable."1/

[1] Joint Logistics Commanders Material Distribution Study, Vol. II, p. 201.

The point of the above discussion is not whether average or discrete throughput costs should be used in modeling the DoD network, although we concede, if for no other reason than the credibility of the end product, that discrete costs are more attractive. The real issue is that a team modeling a distribution network will make many assumptions, generally based on sound logic and experience, and those assumptions will necessarily affect other approaches to the modeling effort. In DoDMDS the use of average rather than discrete depot throughput costs affected the approach for estimating throughput measures. Future modeling efforts will be confronted with similar issues, and only after they are resolved should throughput cost and capacity be estimated.

3. ALTERNATIVE APPROACHES FOR ESTIMATING DEPOT THROUGHPUT MEASURES

STATISTICAL APPROACH

Private industry makes extensive use of statistical methods to estimate depot throughput costs and capacities. The DoDMDS study team also used this approach. They used multiple regression analysis to relate depot variable costs to several shipment workload measures: line items shipped, cubic feet shipped, and dollar value. The regression analysis results were then used to derive difficulty factors for 69 general product groups, and these, in turn, were used to calculate depot throughput costs, maximum depot throughput capacities, maintenance interface costs, materiel relocation costs, and forecasted depot fixed cost increases.

Unfortunately, serious technical issues exist with the statistical methods used by the DoDMDS study team to derive the difficulty factors. Table 3-1 identifies those issues and summarizes our proposed solutions. Those solutions also form the basis for our statistical approach which is described below.

Depot Throughput Costs

The key step in using statistical methods to estimate depot throughput costs is the identification of FPGs. As mentioned previously, an FPG includes all items which receive the same or similar processing functions within the depot, from initial item receipt to final shipment. To illustrate, Table 3-2 shows the FPGs developed by the DoDMDS study group to assess nominal depot costs.

TABLE 3-1. TECHNICAL ISSUES SURROUNDING DoDMDS STATISTICAL ANALYSIS

Issue[1]	Solution
1. Unit of Association. Logical relationship between depot variable cost and dollar value of items shipped is not established.	1. Agree. Do not use dollar value as explanatory variable.
2. Shipment vs. Total Workload. Assumption that shipment workload is representative of the total depot workload is not valid.	2. Disagree. Shipment workload is the proper parameter for network modeling. Regression analysis establishes the component of total depot cost (including receiving, storage, and shipping functions) which varies with shipments. The nonvariable component should be treated as a fixed depot cost.
3. Wholesale and Retail. Assumption that factors based on combined wholesale and retail data can be applied to wholesale shipments only is not valid.	3. Agree. Statistical approach can be used to establish cost differences between wholesale and retail shipments.
4. Linear Relationship. Selection of linear relationship over an exponential regression is of questionable validity.	4. Agree. Use logarithmic regression equation to check for nonlinear relationship between variable cost and depot workload measures.
5. System-Wide Coefficients vs. Specific Products. Assumption that system-wide regression result based on 34 depots can be used for estimating 69 separate product group costs is invalid.	5. Agree. Proposed method uses workload measures for limited number of "functional product groups" as explanatory variable in regression equation. Product groups costs are estimated directly with regression result.
6. Alteration of Regression Constant. Regression constant is arbitrarily allocated to product groups.	6. Agree. Constant term should be added to depot fixed costs, not allocated to shipment variable cost.
7. System-Wide vs. Depot Specific. Assumption that average difficulty factors derived from system-wide data applies equally to each of the 34 depots is not valid.	7. Depends. The need for discrete depot throughput costs must be established. Proposed statistical approach provides discrete costs if required.
8. Movers vs. Nonmovers. Analysis based on data for movers only does not apply equally to nonmovers.	8. Agree. But there is no need to model costs of nonmovers.

[1]See pages 32-33 of 1978 DLAO Report, "An Appraisal of JLC's DoDMDS Study"

To estimate depot throughput costs by FPG, the following annual costs and workload data are required for each depot:

- reported fixed cost (RFC)
- reported variable cost (RVC)
- line items shipped by FPG (L_1, L_2, ... L_j)
- cwt shipped by FPG (W_1, W_2, ... W_j).

TABLE 3-2. FUNCTIONAL PRODUCT GROUPS

FPG	Description
1	Items requiring cold storage
2	Hazardous items
3	Items requiring security storage
4	Small arms
5	Ship, boat, aircraft, and railway equipment
6	Aircraft engines
7	Vehicles
8	Tires
9	Subsistence
10	All other items - large (nonpalletizable items)
11	All other items - small (bin and palletizable items)

The reported fixed costs and reported variable costs for each depot can be derived from available accounting data. Those costs will have to be adjusted to accommodate different depot missions and responsibilities, however.

At many depots, the workload measures (line items shipped and cwt shipped by FPG) can be derived from existing reporting systems. For some depots, however, a special data call may be needed to collect the workload for specific FPGs.

The reported fixed and variable costs can be related to depot workload by multiple regression methods. The regression results would appear as follows:

$$RFC = a_o + a_1 \, RVC \quad (1)$$

$$RVC = b_o + b_1 L_1 + b_2 L_2 + \ldots + b_j L_j$$
$$= b_o + \sum_j b_j L_j \quad (2)$$

It is important to note that both regression equations have "fixed" (a_o and b_o) and "variable" (a_1 and b_j) coefficients. This means that the reported fixed costs and reported variable costs from the standard depot accounts are neither totally fixed nor totally variable. (The DoDMDS data showed RFC to be 45 percent fixed and 55 percent variable, and RVC to be 15 percent fixed and 85 percent variable.) As a consequence, estimates of total fixed cost (TFC) and total variable cost (TVC) must be derived. From equations (1) and (2) we obtain:

$$TFC = a_o + (1 + a_1)\, b_o \tag{3}$$

$$TVC = (1 + a_1) \sum_j b_j L_j \tag{4}$$

Both average and discrete depot throughput costs by FPG are calculated from equations (3) and (4) as shown below:

Average depot fixed cost (FC), expressed in \$/year

$$FC = a_o + (1 + a_1)\, b_o \tag{5}$$

Discrete depot variable costs (VC_j), expressed in \$/cwt for the "j"th FPG

$$VC_j = \frac{(1 + a_1)\, b_j L_j}{W_j} \tag{6}$$

Average depot variable costs, (AVC_j) expressed in \$/cwt for "j"th FPG

$$AVC_j = \frac{(1 + a_1)\, b_j\, TL_j}{TW_j} \tag{7}$$

In equation (7), TL_j is total line items shipped from all depots, and TW_j is total cwt shipped from all depots for FPG "j." A discrete depot fixed cost measure, if needed, can be derived by incorporating a "dummy" variable (D_i) for each depot "i" in regression equation (1). The resulting equation would be:

$$FC = a_o + (1 + a_1)\, b_o + a_i D_i \tag{8}$$

The accuracy and flexibility of the throughput costs results described above may be improved by four refinements.

Additional Workload Measures. Other depot workload measures may be used in lieu of or in addition to line items shipped. Those measures may be used for a single FPG or for all FPGs combined. As an example, equation (2) for depot variable cost can be modified to include total cubic feet shipped (CF_j) by FPG as follows:

$$RVC = b_o + \Sigma (b_j L_j + b_j' \, CF_j) \qquad (9)$$

If the regression coefficient for cubic feet shipped (b_j') is statistically significant, then this depot workload measure is important and should be used to calculate throughput costs. If the coefficient is not significant, the workload measure should be dropped.

Additional Depot Characteristics. The effect on depot throughput costs of such depot characteristics as the degree of automation, the age of the facility, or the layout of the depot can be examined by introducing dummy variables into the regression analysis. A separate dummy variable is needed for each depot characteristic. A dummy variable, DV_k, is set to "1" if the depot characteristic "k" is present and to "0" if the characteristic is not present. Depot characteristics can affect either the "fixed" or "variable" components of depot costs, as illustrated by the following equations:

$$RVC = b_o + b_o' DV_k + \sum_j b_j L_j \qquad (10)$$

$$\begin{aligned} RVC &= b_o + \sum_j (b_j L_j + b_j' \, DV_k \, L_j) \\ &= b_o + \sum_j (b_j + b_j' \, DV_k) \, L_j \end{aligned} \qquad (11)$$

If the regression coefficient of the dummy variable (b'_o in equation (10) or b'_j in equation (11)) is statistically significant, the effect of the depot characteristic should be incorporated into the final throughput cost calculation. If neither coefficient is significant, the depot characteristic variable should be dropped.

Wholesale vs. Retail. DoD depot workloads include both wholesale and retail shipments. Since not all depots have the same retail/wholesale mix (the proportion of wholesale shipments varied from 0.12 to 1.00 in the DoDMDS study), the calculation of throughput costs may be improved by recognizing depot differences. This can be accomplished by incorporating an additional variable, the proportion of total lines shipped wholesale (P_j) for each FPG, into the regression analysis. Equation (2) would then become:

$$RVC = b_o + \sum_j (b_j L_j + b'_j P_j) \qquad (12)$$

For FPGs where the coefficient b'_j is not statistically significant, depot variable costs for wholesale and retail shipments may be considered identical. Where b'_j is statistically significant, the variable costs for wholesale and retail shipments should be considered to be different. Costs for wholesale shipments alone are calculated using the above equation with $P_j = 1.00$. The variable costs of retail shipments can likewise be calculated with $P_j = 0.00$.

Economy of Scale. Depot economies of scale exist if depot workload increases cause proportionately smaller increases in variable cost, i.e., doubling workload does not double cost. Economies of scale can be identified using logarithmic rather than linear regression equations. The logarithmic counterpart of equation (2) is given below:

$$\ln RVC = \ln b_o + \sum_j b_j \ln L_j \qquad (13)$$

The true relationship is shown as:

$$RVC = b_o \, L_1^{\,b_1} \, L_2^{\,b_2} \ldots L_j^{\,b_j} \tag{14}$$

The sum of the regression coefficients ($b_1 + b_2 + \ldots b_j$) is the "scale factor." If the scale factor is less than 1.0, depot economies of scale exist and should be accounted for in the throughput cost calculation. If the scale factor equals 1.0, there is no depot economy of scale and the simpler linear regression equation should be used.

In practice, economy of scale effects can be ignored if the scale factor is greater than 0.8 and depot workload changes do not exceed ± 50 percent from base year values.

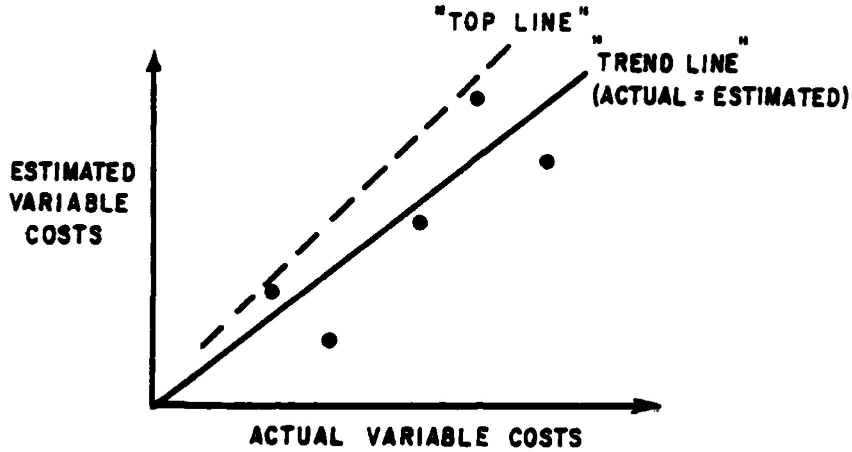
Depot Throughput Capacity

Throughput capacity is expressed in the total hundredweight a depot can process during a period of time, generally one year. In a distribution system as complex as the DoD's, the statistical method for determining depot throughput capacity will necessarily be expressed on a cost (i.e., "dollar effort") basis. This means the historical hundredweight of materiel processed for each FPG is multiplied by the depot throughput cost per cwt to establish a weighted throughput for that FPG. The total weighted throughput for all FPGs establishes a maximum depot weighted throughput capacity (WTP), which, by its statistical nature (i.e., historical cwt of materiel issued times $/cwt), expresses maximum throughput as a dollar value. Such an expression makes it possible to identify the amount of throughput "burden" that a functional product group imposes on a depot, even if that depot had not previously processed the FPG.

Two points require further discussion regarding the use of WTP: (1) the total WTP for a particular depot is only as accurate as the throughput costs established for each general product group; and (2) the maximum WTP values do not establish real world operating constraints. The latter do, however, identify a numeric value, which, if approached or exceeded, indicates that special analysis of that particular depot is required. The analysis may be as simple as visiting the depot and obtaining management's subjective analysis as to whether it can process the required throughput workload or as complex as simulating workload requirements using engineered standards.

Another throughput capacity issue relates to the subjective analysis of potential throughput capacity increases. In the DoDMDS study, the throughput capacity for each depot was assumed to be 25 percent greater than the base year weighted throughput workload. A better approach, we believe, would be to adjust the base year throughput capacity of each depot according to its relative productivity rather than to use a constant percentage adjustment for all depots. If the depot variable cost is used as the weighted throughput measure of depot capacity, then a plot of the estimated variable costs will identify the more productive depots (above the "trend line" where actual cost equals estimated cost) and the less productive (below the line) as illustrated in Figure 3-1. The throughput capacity of depots with below average productivity may then be adjusted to the "trend line" or even to the "top line" of highly productive depots. Either adjustment assumes that the productivity of below average depots can be improved with appropriate equipment and/or management techniques. The validity of this assumption should be examined on a case-by-case basis, however.

FIGURE 3-1. ESTIMATED VS. ACTUAL DEPOT THROUGHPUT CAPACITY



ENGINEERED APPROACH

The engineered approach estimates throughput costs and capacities by simulating depot operations. This approach is not new to the DoD. The DoDMDS study team used it to identify nominal depot costs, based on a network of depots employing state-of-the-art materiel handling techniques, equipment, and facilities. By using nominal costs, existing depot throughput costs could be compared with modernized system costs to assess the viability of capital improvements. Although the objective of the DoDMDS study nominal cost development differs from the engineered development of depot throughput costs, the same basic techniques apply.

Throughput Costs

Four major steps are involved in estimating throughput costs using the engineered approach: identifying FPGs, developing workload requirements for FPGs, simulating workload costs, and converting cost per FPG to cost per general product group (GPG).

Identifying Functional Product Groups. The purpose of this step is to identify FPGs which are standard throughout the DoD. As noted previously, an FPG is defined as materiel that receives similar handling within a depot, from receiving to final shipment. Conceptually, an FPG can be considered to be a collection of specific work centers -- receiving, inspecting, storing, issuing, packing, and shipping -- through which materiel flows in a particular depot. The number of FPGs will probably be less than 20. The engineered throughput costs for each work center can be aggregated to provide a total throughput cost for each FPG.

Developing Workload Requirements. FPGs are characterized by the work centers through which materiel flows. The specific FPGs required can be developed through historical information and often enhanced by special data calls or statistical sampling. To establish FPG workloads, GPG workloads must first be converted to FPG workloads and then the work center workloads must be estimated.

The historical workload for each GPG is expressed both in terms of receipts (number of receipts; average cube, weight, and units per receipt; total cube, weight, and units) and shipments or issues (number of issues; average cube, weight, and units per issue; total cube, weight, and units). Once the GPG workload is defined, then the burden that each GPG places on a particular FPG can be estimated using historical work flows. The total workload for each FPG is then the sum of GPG workloads flowing through the FPG.

The workload at each work center within the depot can be estimated by developing factors (i.e., percentages) for each FPG to be applied against the workload for each work center. For instance, suppose a given FPG had a historical workload of 2,000 receipts, all of which were processed through the storage work center. Some of those receipts went directly to storage, others went to inspection and then to storage. The percentage of those 2,000 receipts that were inspected can be used to estimate the workload at the inspection work center for that FPG.

The actual measure of workload (i.e., cubic feet, hundredweight, number of units) will vary among work centers depending on which measure is related most accurately to cost. In addition, since work centers generally process workload from several FPGs, the total workload for each work center is a sum of the FPG workloads through that center.

Simulating Workload Costs. This step entails simulating the historical work center workload to establish a cost per processing unit (i.e., cubic foot, hundredweight, item, etc.). For each work center, the annual workload is converted into a daily workload. DoD time standards for materiel handling and warehousing are then applied to the cost per hour for labor, equipment, material, storage, etc., to establish direct variable throughput costs. Those costs are then ratioed upward to capture indirect variable costs and to yield a total throughput cost by work center. At this point, all throughput costs must be expressed in \$/cwt. The costs (\$/cwt) for all work centers within a particular FPG are then aggregated to yield a total cost (\$/cwt) for that FPG.

Estimating FPG throughput costs using the engineered approach is a time-consuming and tedious task. Total aggregated engineered costs should correspond to known historical costs. If they do not, then the simulation results must be reassessed.

Converting FPG to GPG. Once the costs (\$/cwt) by each FPG are established, those costs must be converted to a GPG basis. This conversion can be accomplished by identifying the amount (percentage) of GPG materiel that flows through the various FPGs and summing the prorated costs. In essence, the result ($/cwt by GPG) is a weighted throughput cost.

Throughput Capacity

The technique outlined in the statistical approach for estimating depot throughput capacities also applies to the engineered approach. The engineered cost ($/cwt by GPG) is multiplied by the total hundredweight for that GPG to establish the weighted throughput capacity. The GPG weighted throughput capacities are then aggregated to establish a total throughput capacity for the depot.

The principal advantage of the engineered approach is that it permits a detailed assessment of throughput limitations. Since the engineered approach requires depot simulation to identify throughput costs, the simulation model already established can be used to evaluate depot workloads throughout the DoD, assess alternative workload assignments, and develop an improved distribution network.

COMBINED STATISTICAL/ENGINEERED APPROACH

This approach contains the positive attributes of the statistical and engineered approaches, while avoiding many of their limitations. Like the statistical approach, the combined approach utilizes historical depot cost and workload data, thus assuring conformance to prior year totals and trends. Unlike the statistical approach, however, it does not have a limitation on the number of FPGs that can be defined.

The combined approach uses the engineered approach to derive workload weighting factors for each FPG. The weighting factors can be derived from either the average time or average cost to process each FPG through the depots. Thus, the engineering judgment and technical expertise of depot personnel and analysts involved in the engineered approach play an important role. The workload weighting factors and actual workload measures (i.e., line items shipped) are used to compute a weighted workload measure for each depot as follows:

$$WL = \sum_j \omega_j L_j \tag{15}$$

where WL is the depot weighted workload measure, ω_j is the workload weighting factor for each FPG, and L_j represents line items shipped for each FPG. Depot RVC are related to the depot weighted workload measures using a simple linear regression:

$$RVC = b_o + b_1 WL \tag{16}$$

Finally, depot variable cost per hundredweight (VC_j) for each FPG is estimated from the above results, as shown below:

$$VC_j = \frac{b_1 \omega_j L_j}{\omega_j} \tag{17}$$

The workload weighting factors and FPG workload measures (line items shipped and hundredweight shipped) can be averages for all depots or discrete values for individual depots depending on the network analysis requirements.

The effect of additional FPG workload measures, additional depot characteristics, wholesale vs. retail differences, and economy of scale can then be incorporated into the analysis using the statistical approaches previously described.

4. CONCLUSIONS AND RECOMMENDATIONS

THROUGHPUT MEASURES

We recommend two throughput measures be adopted for materiel distribution system analysis: depot throughput cost expressed as a cost per hundredweight by FPG, and depot throughput capacity expressed as hundredweight of processing capability per year. These measures are compatible with distribution network modeling requirements and will enable depot costs to be traded against transportation costs to improve DoD's materiel distribution system efficiency.

DERIVATION OF MEASURES

Existing reporting systems do not provide throughput cost and capacity in the recommended formats. This fact and the *ad hoc* nature of network planning studies, lead to the recommendation that proposed throughput measures be estimated from historical data using a definition of FPGs and an approach tailored to the specific analysis objectives at hand. Three practical approaches exist for estimating the proposed measures: statistical, engineered, and combined.

RELATED ISSUES

Three research-related issues affect the approach for estimating depot throughput cost and capacity. First, the number of FPGs required to conduct throughput cost analysis must be established. If more than about ten FPGs are needed, the validity of the statistical approach may be compromised and the engineered or combined approach will have to be used. Below ten FPGs, all three approaches are practical.

A second issue concerns the amount of averaging required to reduce the system-wide transactions, depots, transportation links, and FPGs to a manageable number for modeling purposes. If problems are caused by system-wide averaging, consideration must be given to partitioning the system by geographic area or military service.

A last related issue is the impact of using system-wide average depot throughput costs for each product group versus using discrete depot costs. Discrete costs can be simply handled with the statistical and combined approaches, but greatly increase the workload with the engineered approach.

We recommend these issues be specifically addressed before committing resources to estimating depot throughput for distribution system analysis.

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Study proposes cost per hundredweight by functional product group (FPG) as the measure of depot throughput for DoD materiel distribution systems analysis. It also proposes depot throughput capacity be measured in hundredweight of materiel processed per year. These measures will facilitate tradeoffs between transportation and depot costs needed for improving the efficiency of DoD materiel distribution. Three alternative methods for estimating depot throughput costs and capacities are presented.

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